Using GPS to Determine

Position Error Corrections

Purpose

- **To describe a pitot static Flight Test Technique**
  - ~ review earlier approaches to using GPS
  - ~ explain limitations of earlier methods
  - ~ show how limitations are alleviated
- **To describe the pros and cons of the proposed FTT**
- **To show test results that validate the proposed method**
  - ~ compare GPS results to traditional methods

Why use GPS for PEC?

- **The attraction**
  - ~ **no aircraft modification required**
    - » **no trailing cone or aircraft plumbing mod**
    - » **no flight test boom**
  - ~ **no limitation on speed or altitude**
    - » **can be done down to near stall**
    - » **any altitude**
  - ~ **easy data reduction**
    - » **no correlation with pace aircraft, ground radar, or other references required**

The Basic Idea

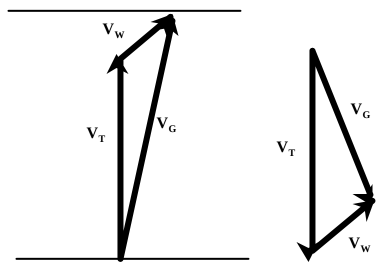
- **Using the precision of GPS**
  - ~ **accurate ground speed cheaply and easily obtained in any aircraft**
  - ~ **get true airspeed from ground speed as in the traditional ground course FTT**
    - » **requires negating the effect of wind**
  - ~ **with true airspeed, can obtain speed position error correction (ΔV_{pc})**

$$(V_i + \Delta V_{ic} + \Delta V_{pc} + \Delta V_c)/\sigma^{1/2} = V_{true}$$

  - ~ **note: still requires calibrated (preferably sensitive) airspeed indicator**

Traditional Ground Course

- To remove the effect of wind
  - ~ fly a heading directly between two ground markers, allowing the aircraft to drift
  - ~ repeat 180^0 opposite heading
  - ~ use distance/time to get component of ground speed
  - ~ average the two ground speeds



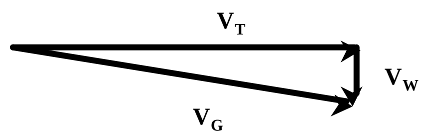
Old GPS Method 1

- Do the same as traditional ground course method
  - ~ but must fly directly into and away from the wind
  - ~ if not, no way to determine the components of ground speed
    - » unknown wind gives unknown contribution to Vg

- Practical problem
  - ~ determining wind direction
  - ~ done by flying until heading = track
  - ~ not sufficiently accurate for PEC determination

Old GPS Method 2

- Same as method 1, but
  - ~ fly directly perpendicular to the wind
  - ~ use average ground speeds and drift angle to solve for Vtrue



- Same problem as method 1
  - ~ if not directly perpendicular to the wind
    - » unknown effect on ground speed

Old GPS Method 3

- Same as traditional ground course method
  - ~ fly directly towards a GPS waypoint 8,000 nm away
  - ~ determine ground speed by timing GPS range changes
    - » this gives normal component of ground speed
      - • no crab effect with remote waypoint
    - » average both towards and away components

- Practical problems
  - ~ Update of range on handheld GPS units is from 1 to 3 second interval
    - » okay only for range intervals that result in long times relative to timing errors

Old GPS Method 4

- **Same as traditional ground course method**
  - ~ **fly true north or south**
  - ~ **determine ground speed by timing GPS *latitude* changes**
    - » **hack watch when whole latitude “rolls over”**
      - • **minimizes update rate problems associated with range to a waypoint**
    - » **reverse course and repeat**

- **Practical problems**
  - ~ **minimal problems for low speed data points**
  - ~ **higher speeds requires longer runs, larger times**
    - » **possible wind change over large distances**

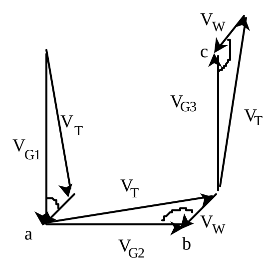
Old GPS Method 5

- **Horseshoe track method (*Kitplanes*, Feb 95)**
  - ~ **fly three legs with each perpendicular ground tracks, noting GPS ground speed on each**
  - ~ **determine true airspeed by solving three equations in three unknowns**

- **Practical problem**
  - ~ **only problem is the need to fly close to the ground, tracking perpendicular ground references**

Old GPS Method 5

- **Horseshoe track method**
  - ~ **fly three legs with each perpendicular tracks, noting GPS ground speed on each**
  - ~ **determine true airspeed by solving three equations in three unknowns**



Old GPS Method 5

- **Solving three equations:**

$$\text{True airspeed}: \; V_T = \frac{1}{2}\sqrt{\left(V_1^2 + V_2^2 + V_3^2 + V_1^2 \times \left(\frac{V_3^2}{V_2^2}\right)\right)}$$

$$\text{Wind velocity } V_W = \sqrt{\left(\frac{V_1 - V_3}{2}\right)^2 + \left(\frac{V_2 - V_1 \times V_3 / V_2}{2}\right)^2}$$

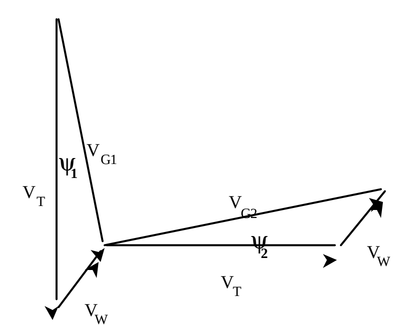
$$\text{Wind direction } y_W = \tan^{-1}\frac{\left(V_2 - V_1 \times V_3 / V_2\right)}{\left(V_1 - V_3\right)}$$

Old GPS Method 6

- **Almost all GPS units show both ground speed and ground track at the same time**
- **Using more information from accurate GPS**
  - ~ **less time spent taking data (more data/lb)**
  - ~ **less opportunity for pilot to be off condition**
- **Method**
  - ~ **fly two perpendicular headings**
  - ~ **record ground speed and track**
  - ~ **allows solving for wind direction, speed, and true airspeed**

Old GPS Method 6

- **If we know Vg_1 and Vg_2 and track angles y_1 and y_1**
  - ~ **Then we can write two equations in two unknowns, Vt and Vw**
  - ~ **With Vt and Vw we can also solve for wind direction**



Old GPS Method 6

- **Solving the two equations for the two leg speed and track method:**

$$\text{True airspeed } V_T = \frac{V_{G_2}^2 - V_{G_1}^2}{V_{G_2}\cos(j_2) - V_{G_1}\cos(j_1)}$$

$$\text{Wind velocity } V_W = \left[V_{G_1}^2 + V_T^2 - 2V_T V_{G_1}\cos(j_1)\right]^{1/2}$$

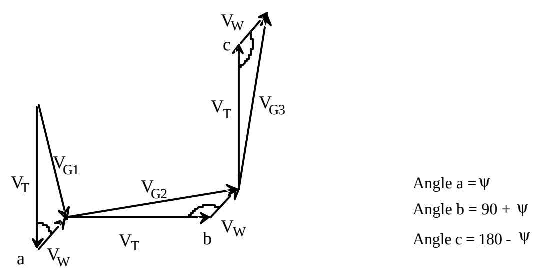
$$\text{Wind direction } y_W = \sin^{-1}\left[\frac{V_{G_1}}{V_W}\sin(j_1)\right]$$

Old GPS Method 6

- **Practical problem**
  - ~ **accuracy and resolution of aircraft heading**
  - ~ **leads to large scatter in results**
    - » **10 to 15 kts standard deviation typical**
- **Conclusion**
  - ~ **unsuitable for PEC**

Proposed Method

- **Horseshoe heading method**
  - ~ **fly three legs with each perpendicular headings, noting GPS ground speed on each**
  - ~ **determine true airspeed by solving three equations in three unknowns**



Equations

- **Solving the three equations for the horseshoe heading method:**

$$\text{Wind direction } \psi = \tan^{-1}\left[\frac{-V_{G1}^2 + 2V_{G2}^2 - V_{G3}^2}{V_{G3}^2 - V_{G1}^2}\right]$$

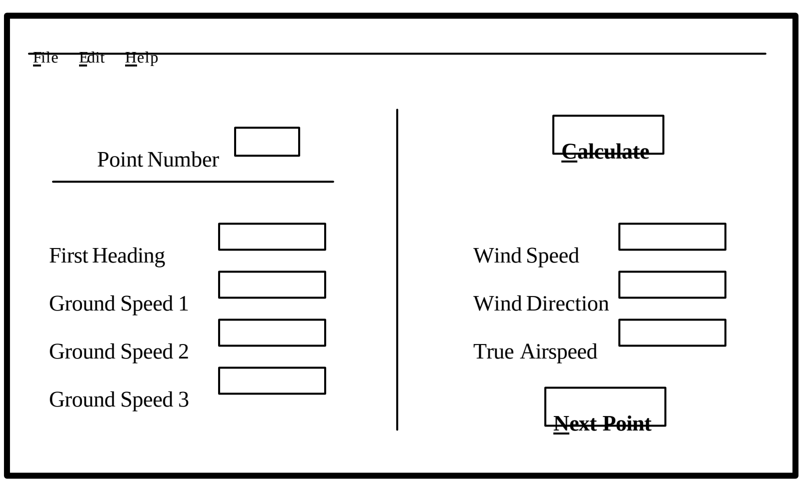
$$\text{Wind velocity } V_W = \tfrac{1}{2}\left[V_{G3}^2 + V_{G1}^2 \pm \sqrt{\left(V_{G3}^2 + V_{G1}^2\right)^2 - \left(\frac{-V_{G1}^2 + 2V_{G2}^2 - V_{G3}^2}{\sin\psi}\right)^2}\right]^{\frac{1}{2}}$$

$$\text{True airspeed } V_T = \sqrt{\frac{V_{G3}^2 + V_{G1}^2}{2} - V_W^2}$$

Software

- "GPS True"
  - ~ Windows 95 program
    - » available on http://www.ntps.com
  - ~ Inputs
    - » Initial heading
    - » V_{G1}, V_{G2}, and V_{G3}
  - ~ Assumptions
    - » left turns between stable points
    - » indicated speed, altitude, wind speed & direction, and temperature constant on all three points
  - ~ Output
    - » wind speed & direction, true airspeed
- Excel spreadsheet also available

"GPS True"



Excel Spreadsheet

		Heading	Vg1	Vg2	Vg3	Wind dir	Vwind	Vtrue GPS
	System	(deg mag)	(kts)	(kts)	(kts)	(deg)	(kts)	(kts)
1	Copilot	180	107.3	93.2	93.2	45	10.0	100.0
2	Duchess	270	126.0	143.0	138.0	332	12.9	131.5
3	Duchess	180	143.0	138.0	127.0	341	8.5	135.0
4	Duchess	90	138.0	127.0	126.0	310	7.8	131.9
5	Duchess	360	127.0	126.0	143.0	312	12.0	134.7
6	Duchess	270	135.0	152.0	143.0	344	14.2	138.3

- **available on http://www.ntps.com**

Validation Test

- **The proposed FTT and data reduction were tried and the results compared to truth data**
  - ~ **aircraft: SW3 Merlin**
    - » **calibrated instruments**
  - ~ **GPS unit: Garmin 95**
  - ~ **truth data: trailing cone and Kiel tube**
    - » **truth data results: s = 0.384 kts from smooth curve fit**

- **The trial was conducted in conjunction with a two week introductory course on flight testing CAFB Cold Lake, Canada**

Winds During the Trial

- **The points were spread out over 3 sorties and nearly 2 hours**
- **Reduction of GPS data gave the following winds:**

	Wind Speed	Wind Direction	Approx. Time of Day
1	17.4	283	9:30
2	15.5	286	9:40
3	13.5	285	10:15
4	12.5	286	11:00
5	1.0	120	11:10
6	11.3	252	11:00

- **Point #5 was eliminated due to the unreasonable winds and unlikely deviation of PEC compared to other points**

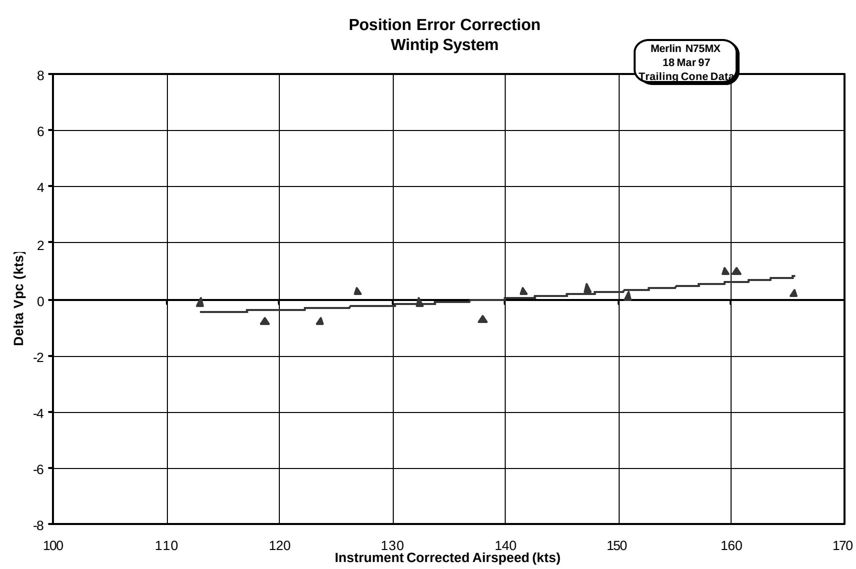


Figure 1. Trailing Cone Data

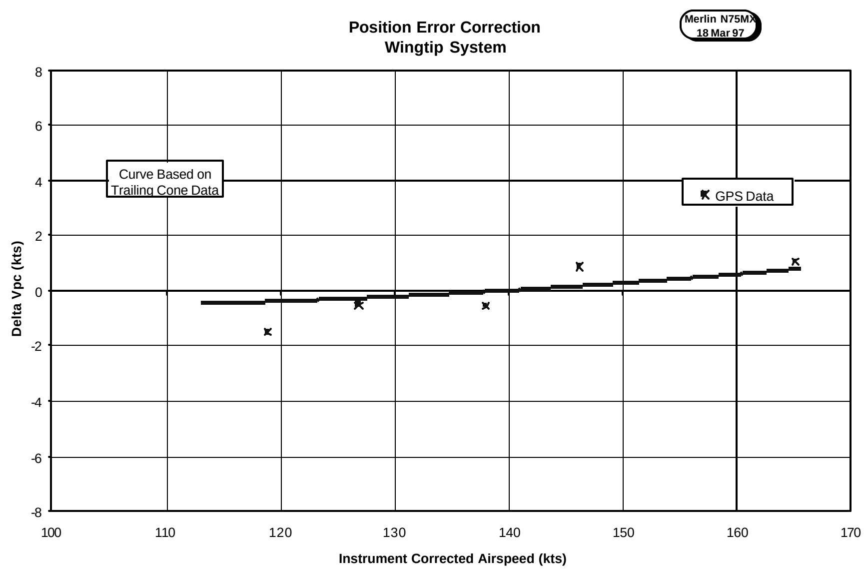


Figure 2. GPS Data

Differential GPS?

- Trials were done with civilian code GPS
- Differential GPS or "P" codes would significantly improve accuracy
  - ~ but accuracy of position
  - ~ not necessarily accuracy of ground speed
- Most errors result in a bias that does not rapidly change with time
  - ~ atmospheric effects
  - ~ DOP
  - ~ military dithering
- GPS speed
  - ~ if time differentiated position, unaffected by a constant bias
  - ~ if doppler, unaffected by position errors

Conclusions

- **“Horseshoe heading” method works well**
- **Generally excellent correlation**
  - ~ s **of trailing cone data from best fit curve = 0.38 kts**
  - ~ s **of trailing GPS data from the same curve = 0.53 kts**
  - ~ **all ground course methods assume zero error in total pressure measurement**
- **Proposed method should be applicable to a wide variety of aircraft**
  - ~ **successfully used on**
    - » **several light aircraft**
    - » **Merlin, MB-326 (~0.6 M), C-130, SK-35 (~.9 M)**